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Computer-controlled processing of radar precipitation signals and lightning data

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COMPUTER-CONTROLLED PROCESSING OF RADAR PRECIPITATION SIGNALS AND LIGHTNING DATA

BY

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THESIS

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ABSTRACT

A system for the simultaneous processing of radar precipitation signals and lightning stroke location data has been designed. The system is to be used for the purpose of determining spatial and temporal correlations of lightning and thunderstorm precipitation.

This system has been developed to gain further information about the cause-effect relationship between lightning stroke activity and thunderstorm precipitation.

Data acquisition and processing is accomplished through the use of an AN/FPS-18 radar set, an SCC-650 digital computer system, a radar interface, and a set of lightning detectors.

The radar set provides information on precipitation activity in a circle of radius fifty miles centered at Vichy, Missouri. Lightning stroke azimuth and range are to be obtained from the lightning detectors.

The information from the radar set is supplied to the computer through a modem data conversion interface. A lightning data interface will be designed and built in the near future. The computer is used as a high-speed data processor. Its primary function is to reformat the radar and lightning data and store it on magnetic tape in a form suitable for off-line processing.

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LIST OF ABBREVIATIONS AND MNEMONICS

TP	Timing pulse
NP	North pulse
ACP	Azimuth change pulse
TGT	Target
EXTINT	External interrupt
SELRDR	Select radar
TTA	Transfer to accumulator
RDR	Radar
TFR	Transfer
TMR	Terminate
TMRCLR	Terminate-clear
RDRWRD	Radar word
WTACP	Wait for azimuth change pulse
WTLNTH	Wait length
WRTFLG	Write flag
BITCNT	Bit count
WRDCNT	Word count
TPCNT	Timing pulse count
ACPCNT	Azimuth change pulse count
GAPFLG	Gap flag
NPFLG	North pulse flag

I. INTRODUCTION

Postulates concerning the cause-effect relationships between thunderstorm precipitation and lightning strokes have been offered for many years. Several methods of study have been attempted, many involving the manual recording of precipitation rates and corresponding lightning stroke activity. An automated system would provide a much more accurate method of collecting data. The precise location and time relationship between lightning and precipitation data could be obtained.

The availability of a radar set led to the decision to use this device for acquisition of precipitation signals. A method of relating lightning strokes to geographically corresponding precipitation rates was desired. Direct recording of precipitation rates on film or magnetic tape would not suffice because it would be difficult to simultaneously record the location of lightning strokes and relate the locations of strokes and precipitation rates. An SCC-650 computer was selected for this purpose. This computer is a small, high-speed, digital computer. It has a random access, twelve bit, 4096 word memory, and employs fully-parallel processing [6].

The amount of data acquired from a thunderstorm would be extremely large with respect to the computer's memory capacity. The computer's entire memory would fill in only

34 seconds. This factor led to the implementation of a magnetic tape recorder as the storage device. The magnetic tape unit consists of a Kennedy Model 1400R incremental tape recorder with an integrated circuit interface.

The recorder is equipped with 8½ inch reels of tape which, at the character density of the data stored, will hold approximately 3.3 hours of radar data.

The radar set is located at Vichy, Missouri, but can be remotely controlled, and monitored from a plan position indicator in the Computer Research Laboratory in the Electrical Engineering building. The appropriate radar signals are transmitted to the plan position indicator over a voice-grade telephone line. The indicator unit demodulates the signals and converts them to pulses.

The signals are then routed through an interface and into the computer, where they are processed by software, formated, and stored on magnetic tape. The software package also contains provisions for storing lightning data from a set of magnetic field detectors on tape. The system described here does not include the lightning data system or interface.

II. REVIEW OF THE LITERATURE

A. Precipitation-Lightning Study Methods

There has been a considerable amount of study concerning precipitation and lightning strokes accomplished in the past. Many of the more recent studies have involved the use of radar sets for precipitation information, and magnetic field detectors for lightning data acquisition. Very little work has been done in the area of automatic, or computer-controlled processing of both precipitation and lightning data, however.

Most of the previous studies involved manual recording of either precipitation rates or lightning data, or both. Frank, 1966 [1], in his studies of shower distribution over the Florida peninsula, utilized a graph of the geographic area under surveillance by a radar. Observers placed check marks on the graph where precipitation signals appeared. There were no lightning studies involved in this work.

A slightly more sophisticated approach to precipitation studies was Myer's, 1964 [2], investigations in Pennsylvania. A movie camera was positioned in front of a radar screen; thus a permanent, accurate record of precipitation data was obtained.

Smith, 1968 [3], designed a system for processing radar data which is very similar to the system described here, except that again lightning data was not acquired. A radar set was employed for acquisition of precipitation echoes, a PDP-8 computer was used to format the data, and a magnetic tape recorder was used for data storage. Timing problems, due to the high data rates of the radar set, were experienced which were very similar to the ones the author of this paper encountered.

There has been very little work done in the area of automatic processing of lightning data. Lightning detectors have been used extensively, but the data from the detectors is usually displayed on a cathode ray tube, and not automatically related, according to location, to corresponding precipitation rates.

B. Real Time Data Processing

Several of the concepts involving programming for dynamic buffering and interrupt service routines, as described by Desmonde [4] and Martin [5], were used by the author.

III. SYSTEM DESCRIPTION

This section presents a general description of the system. See Figure 1 for a block diagram.

Acquisition of precipitation signals is accomplished by the radar set. A coordinate data transmitter at the radar site quantizes the video and transmits, over a telephone line, signals which carry range and azimuth information on targets. Each revolution of the radar antenna produces a circular pattern of target information. This circular pattern is divided into 256 azimuth sectors, each 1.4° wide.

The sectors are divided into 64 range blocks, each representing approximately 3/4 of a mile in range (see Figure 2). A north pulse is generated each time the antenna passes through north, which provides a geographical reference for the data in each revolution. In addition, an azimuth change pulse is generated to represent the beginning (range = 0) of each azimuth sector, and a timing pulse signifies the beginning of a range block. These three signals, in addition to a signal which indicates the presence of targets, are transmitted over a voice-grade telephone line to the plan position indicator in the Electrical Engineering building. This radar monitor demodulates the four signals and each is then applied to the monitor interface.

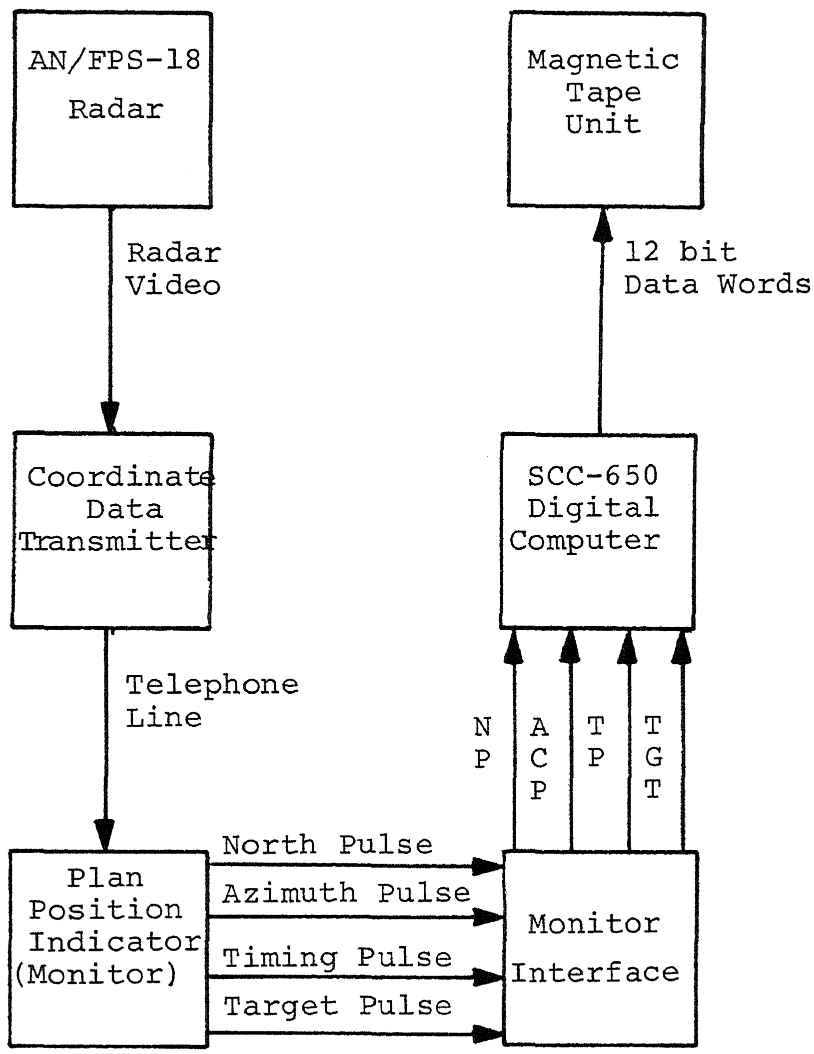


Figure 1. Block Diagram

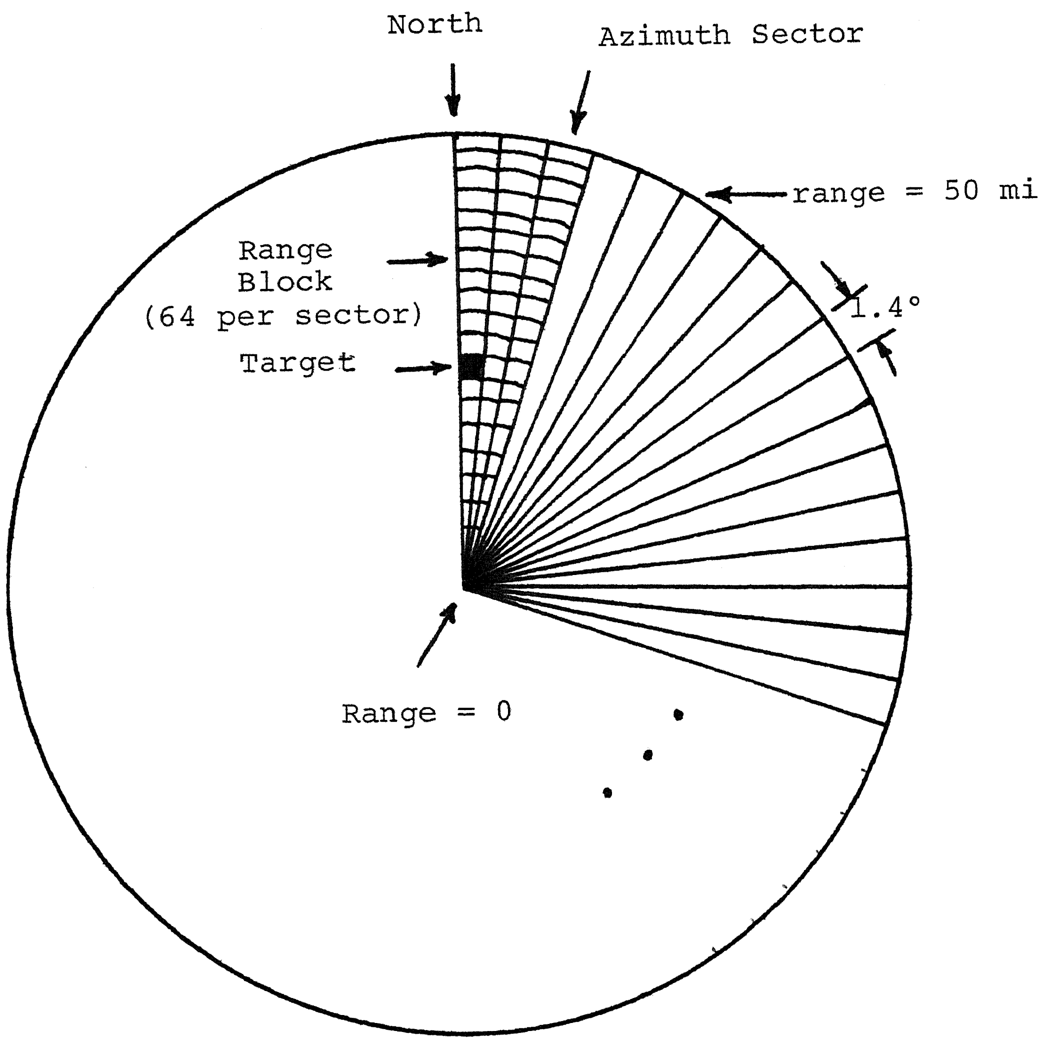


Figure 2. Radar Data Pattern

The signals, as they are available from the monitor, are not of the proper amplitude for input to the computer. In the interface, level conversion is performed on the signals to make them compatible with the input-output buss of the computer. The interface also contains the necessary buffers and control logic.

The signals are inserted into the computer's accumulator as shown in Figure 3.

0	1	2	3	4	5	6	7	8	9	10	11
								NP	ACP	TP	TGT

Figure 3. Accumulator Format

The computer program uses the north pulse (NP), azimuth change pulse (ACP), and timing pulse (TP), to determine the geographical location of the targets (TGT) which appear in bit 11 of the accumulator, and formats them accordingly.

A magnetic tape recorder accepts the data from the computer's memory and stores it on magnetic tape for off-line processing.

IV. SYSTEM OPERATION

A. Radar [7]

An AN/FPS-18 radar set is used to acquire precipitation data. The transmitted energy from the radar has a 10 centimeter wavelength, and is radiated in a beam 1.4 degrees wide with a 30 degree cosecant squared pattern in the vertical plane. The radar has a pulse repetition rate of 1200 pulses per second, and each pulse produces range information at the azimuth at which the antenna is positioned.

The antenna completes one revolution every 11.3 seconds, and is fixed in elevation. Each time the antenna motion passes through north, a north pulse (NP) is generated. In addition, an azimuth change pulse (ACP) is generated every 1.4 degrees of antenna motion. These north and azimuth change pulses are routed to the coordinate data transmitter.

Video pulses are split into 64 range blocks in each 1.4 degree sector (see Figure 2). The beginning of a range block is indicated by the presence of a timing pulse (TP). Target returns are recorded on a storage tube which contains an 8×8 matrix of dots, one dot for each range block. This storage tube records the returned video signals from forty pulses in each azimuth sector.

If a target pulse was recorded in a particular range block some pre-determined number of times out of the possible forty returns, the presence of a target is indicated when the storage tube is read. The operator has the freedom to select the number of returns required out of the possible forty before a target is indicated in a range block when the tube is read out.

B. Coordinate Data Transmitter

The coordinate data transmitter sends information down a voice-grade telephone line to the plan position indicator (refer to Figure 4). This information consists of a north pulse every 11.3 seconds, an azimuth change pulse every 44 milliseconds, a timing pulse every 0.69 millisecond, and the presence of targets coincident with the timing pulses, as the targets occur. These signals are presented to the plan position indicator serially, in the form of frequency modulated tones, a different frequency for each piece of information. Demodulation of these signals is accomplished in the indicator unit. The four signals are separated and converted into pulses, and these pulses are used to generate the display on the CRT, and are also transmitted to the monitor interface.

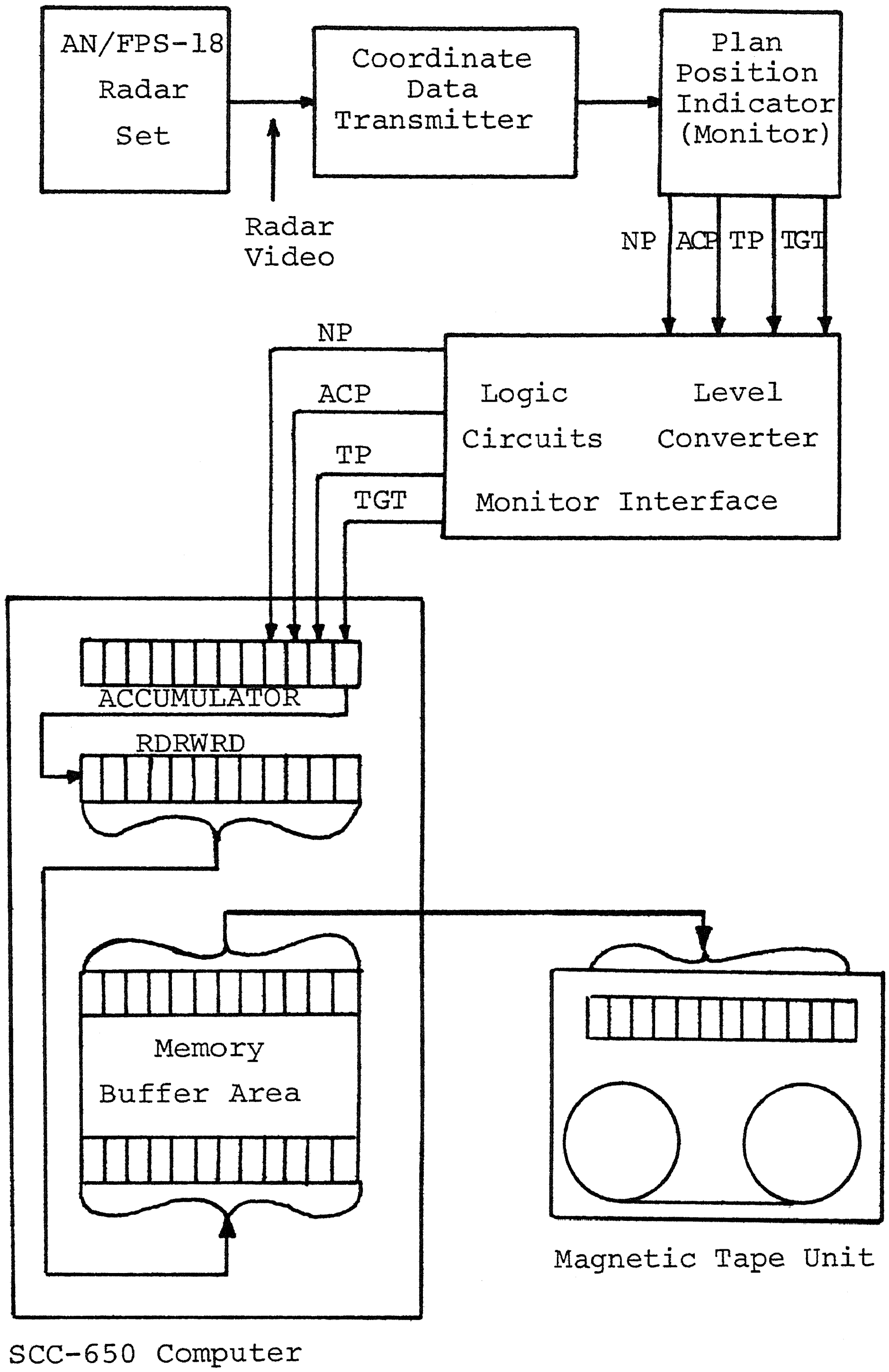


Figure 4. Detailed System Diagram

C. Monitor Interface

The data signals are each routed to a level converter where they are converted from their assertion and non-assertion levels to +5 and 0 volts, respectively. From the level converters, the signals are connected to logic gates, where each is conditioned with a "transfer to computer" command. The timing pulse is also used to interrupt the computer.

D. Computer Processing

When an interrupt is received from the monitor interface, the computer responds with a "transfer to accumulator" command. This instruction causes the four pieces of data to be loaded, in parallel, into the accumulator in the computer. The computer examines the data and records the presence of a target in the particular range block by inserting a one in the proper bit of a word in memory. If no target is present, a zero is stored in the corresponding bit position.

A memory map of the storage area is shown in Figure 5. The leftmost bit of each 12 bit word is a code bit. The collection of code bits creates a pattern of 1's and 0's used to determine the location of the north pulse, the beginning of each azimuth sector, and the location of the lightning azimuth and range data in the data storage area and on tape.

CODE BIT	Precipitation Data											
1	0	0	0	0	1	1	1	0	0	0	0	North Sector
1	0	0	0	0	0	1	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	X	X	
1	0	0	0	0	0	0	0	0	0	0	0	Second Sector
0	0	0	0	0	0	0	1	1	0	0	0	
0	0	0	0	1	1	1	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	X	X	
1	0	1	1	1	0	1	1	1	0	0	0	Lightning Data
1	1	0	0	1	1	0	1	1	1	0	0	
1	0	0	0	0	0	0	0	0	0	1	0	Third Sector
0	0	0	0	0	0	0	0	0	0	1	0	
0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	X	X	

(X's indicate extraneous bits)

Figure 5. Memory Map

The data in an azimuth sector is represented by six words in memory. The first word (excluding the first, or code bit) represents the first 11 range blocks of the sector. The next word represents the next 11 blocks, etc.; therefore, the second bit of the first word corresponds to a range of 0 to 3/4 mile geographically, the third bit 3/4 to 1 1/2 miles. The tenth bit of the sixth word represents the last range block of the sector, and the remaining two bits of this word are extraneous.

The next sector of radar information is represented by the next six words in memory. When lightning data is present, it is stored in memory at the end of the sector information, in the form of two 12 bit words.

Actually, the storage area in memory will seldom contain more than five or six words because the computer program makes an attempt to write the top word in the memory area onto the magnetic tape during the time between timing pulses. Once a word has been written onto tape, each of the remaining words in memory is moved up one position. When no lightning information is present, the magnetic tape unit can keep the storage area in memory empty. If lightning data becomes frequent, however, the magnetic tape unit lags behind the data input rate, and the storage area in memory starts to grow. The words coming into the memory storage are stored at the bottom of the area.

E. Data Storage

The magnetic tape unit accepts the data from the computer in the form of 12 bit words, but the words are divided into two six bit sections and stored on tape as shown in Figure 6.

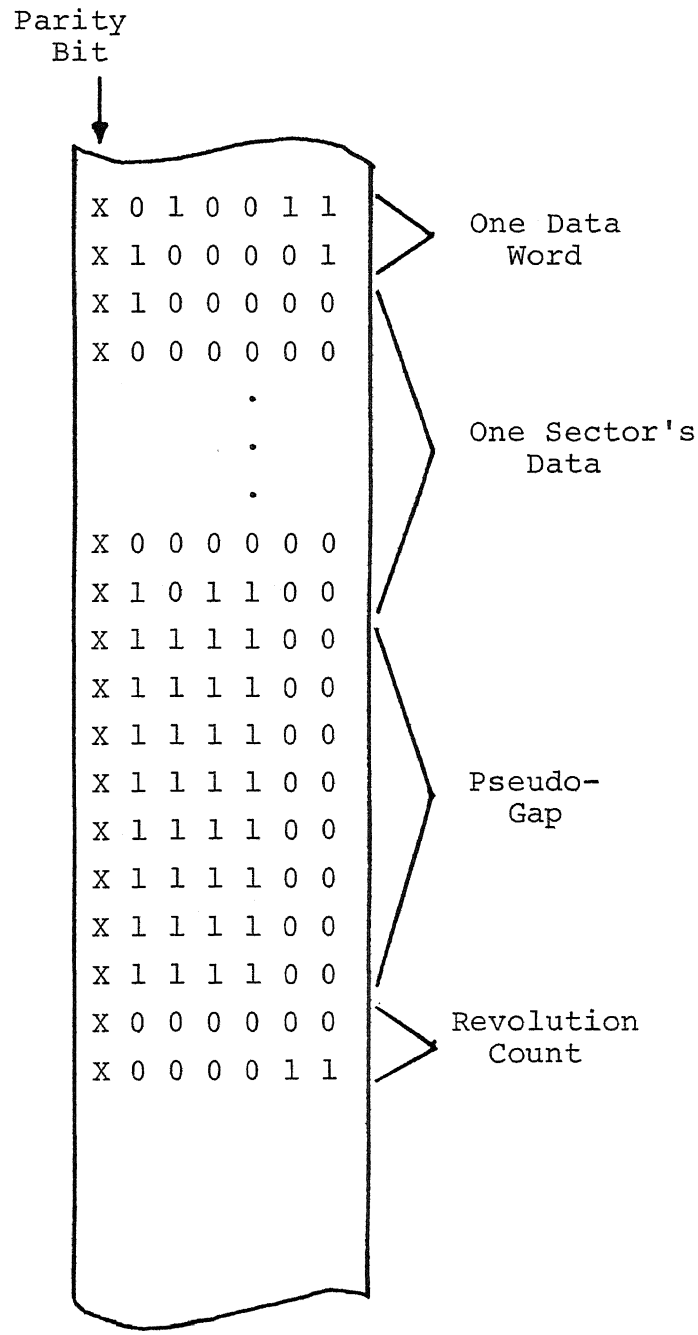


Figure 6. Magnetic Tape Data Storage Format

V. CONCLUDING REMARKS

The effort to design and build a system for processing precipitation and lightning data has been quite successful. To realize the full capability of the system, a great deal of work remains. A computer program will be written which will search the magnetic tape for lightning data in some geographic area around the location of the lightning stroke. Investigation of the precipitation data in this same region during preceding and following revolutions would be desirable also.

Elevation information on precipitation is very important for correlation studies; therefore, an antenna which produces elevation information is needed.

The author intends to work on these and other related problems in the future.

APPENDIX A

DETAILED DESCRIPTION OF THE MONITOR INTERFACE

The monitor interface contains level converters which serve to make the radar signals compatible with the input-output buss of the computer (see Figure 7). The computer accepts 0 or +8 volts, 0 volts corresponding to a logic one and +8 volts corresponding to a logic zero. In the following description, "high" refers to +5 volts, and "low" refers to 0 volts.

Assertion signals from the radar monitor are -40 v, -30 v, +10 v, and +30 v. The level converters convert these assertion signals to +5 volts. The non-assertion signals are 0 volts in all cases. The +5 volt signals are used because of the ready availability of +5 volt integrated circuit logic gates for construction of the interface. Also contained in the interface are the logic circuits required to service the input-output commands from the computer.

Each of the four signals from the radar set (north pulse, azimuth change pulse, timing pulse, and target pulse), after level conversion, is connected to separate NAND gates where they are conditioned with a "transfer" command (see Figure 8). The timing pulse is also connected to the "clock" input of the external interrupt (EXTINT) flip-flop (see Figure 9).

When the computer executes the select radar command, SELRDR- becomes low. When a timing pulse arrives at the EXTINT flip-flop, EXTINT becomes high.

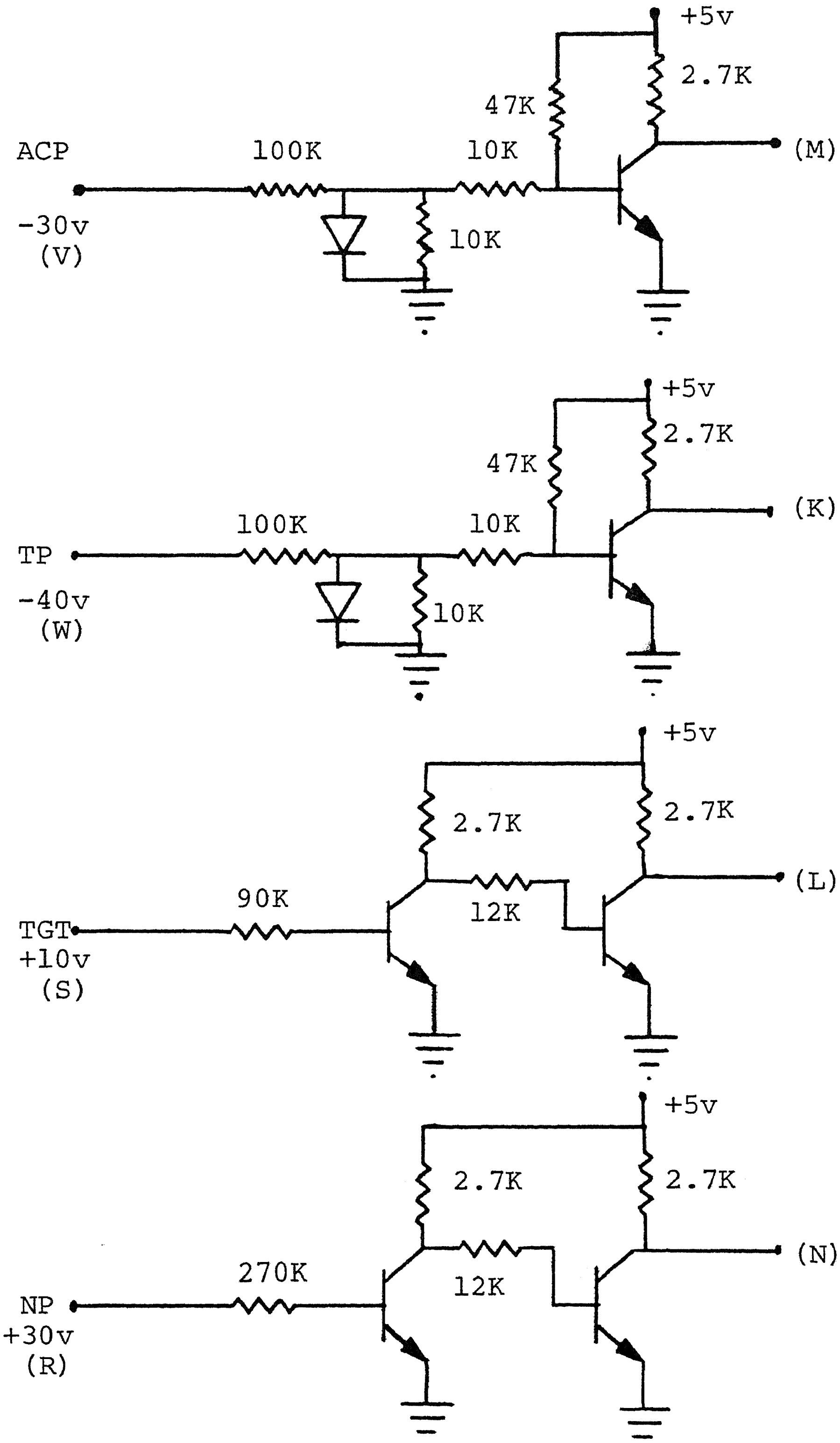


Figure 7. Level Converters

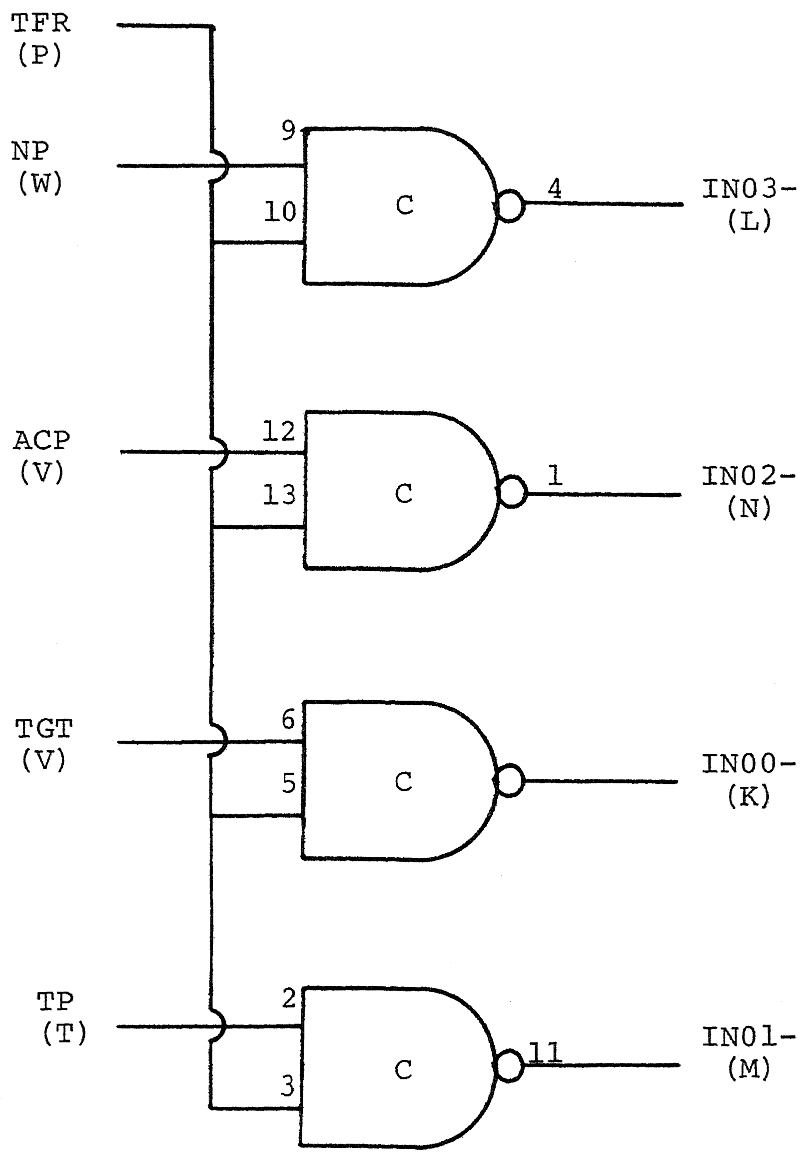


Figure 8. Logic Diagram Number 1

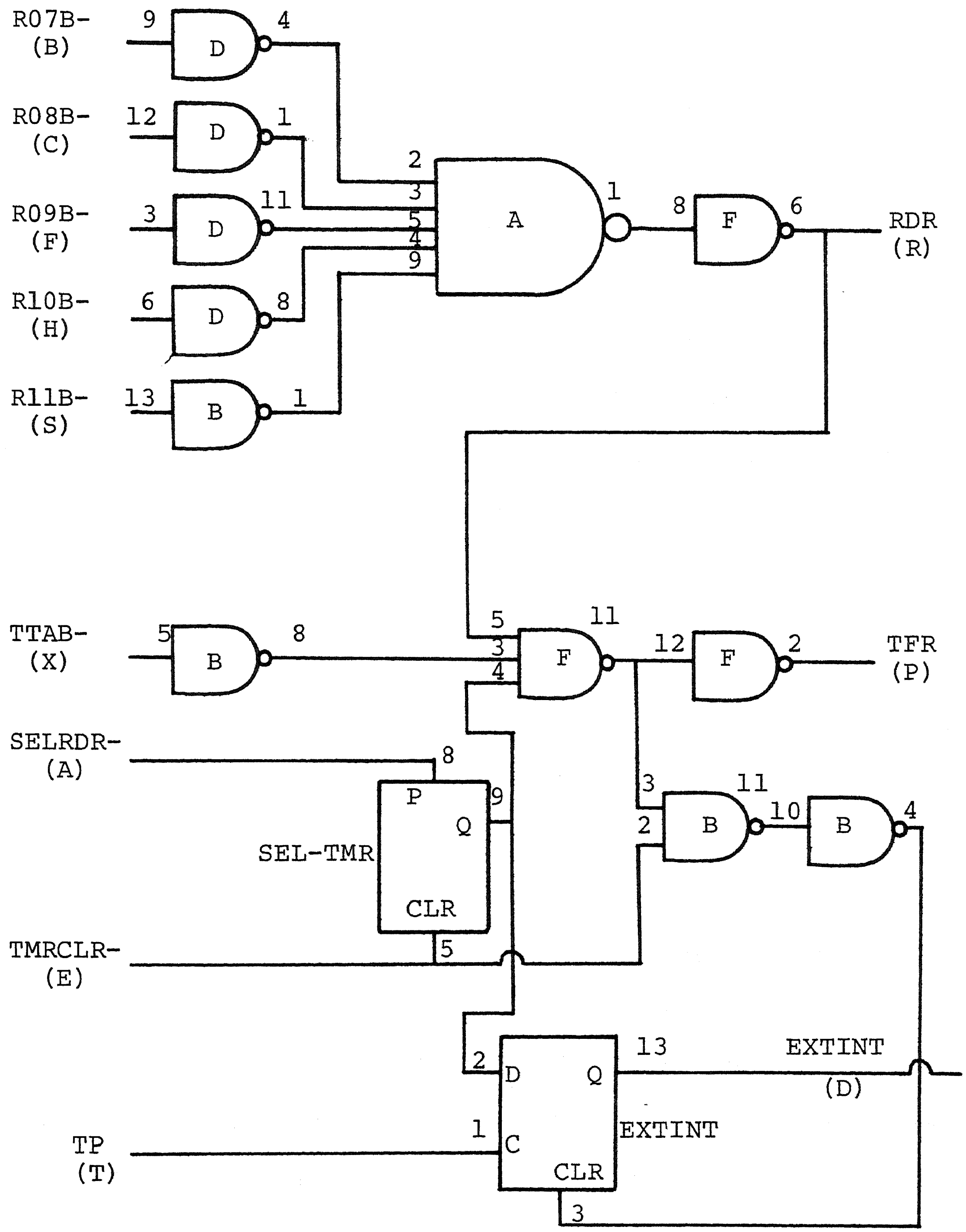


Figure 9. Logic Diagram Number 2

The EXTINT signal is used to interrupt the computer. The interrupt causes the computer to leave the portion of the program under execution and jump to the location stored in memory location octal 7777 ('7777), which is the beginning address of the processing program. The first command encountered in the program is "transfer to accumulator from the radar" (TTA '37). TTA '37 is decoded in the radar interface and causes RDR to become high and TTAB- to become low. When TTAB- and RDR reach these states, with SELRDR- low, TFR becomes high and the north, azimuth, timing and target information is gated into bits 8, 9, 10, and 11, respectively, of the accumulator in the CPU for processing by the computer program.

The TFR signal is used to indicate to the computer that the interface is ready to input data to the accumulator (see Figure 10).

If a "terminate radar" (TMR '37) command is decoded in the interface, the TMR signal becomes low, causing TMRCLR- to become low (see Figure 11). TMRCLR- is used to reset the select-terminate flip-flop and to reset the EXTINT flip-flop which inhibits more interrupts from occurring until another SELRDR-, TTA '37, and timing pulse is received. Depressing the START button on the computer console also causes TMRCLR- to become low, again inhibiting further interrupts as before.

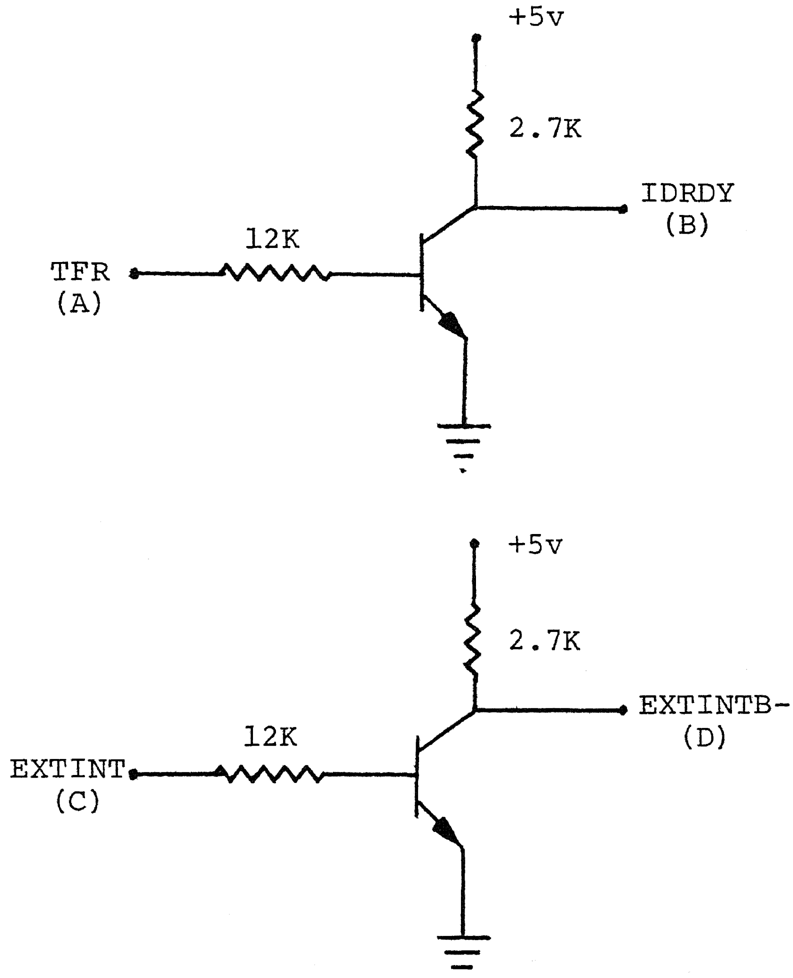


Figure 10, Logic Diagram Number 3

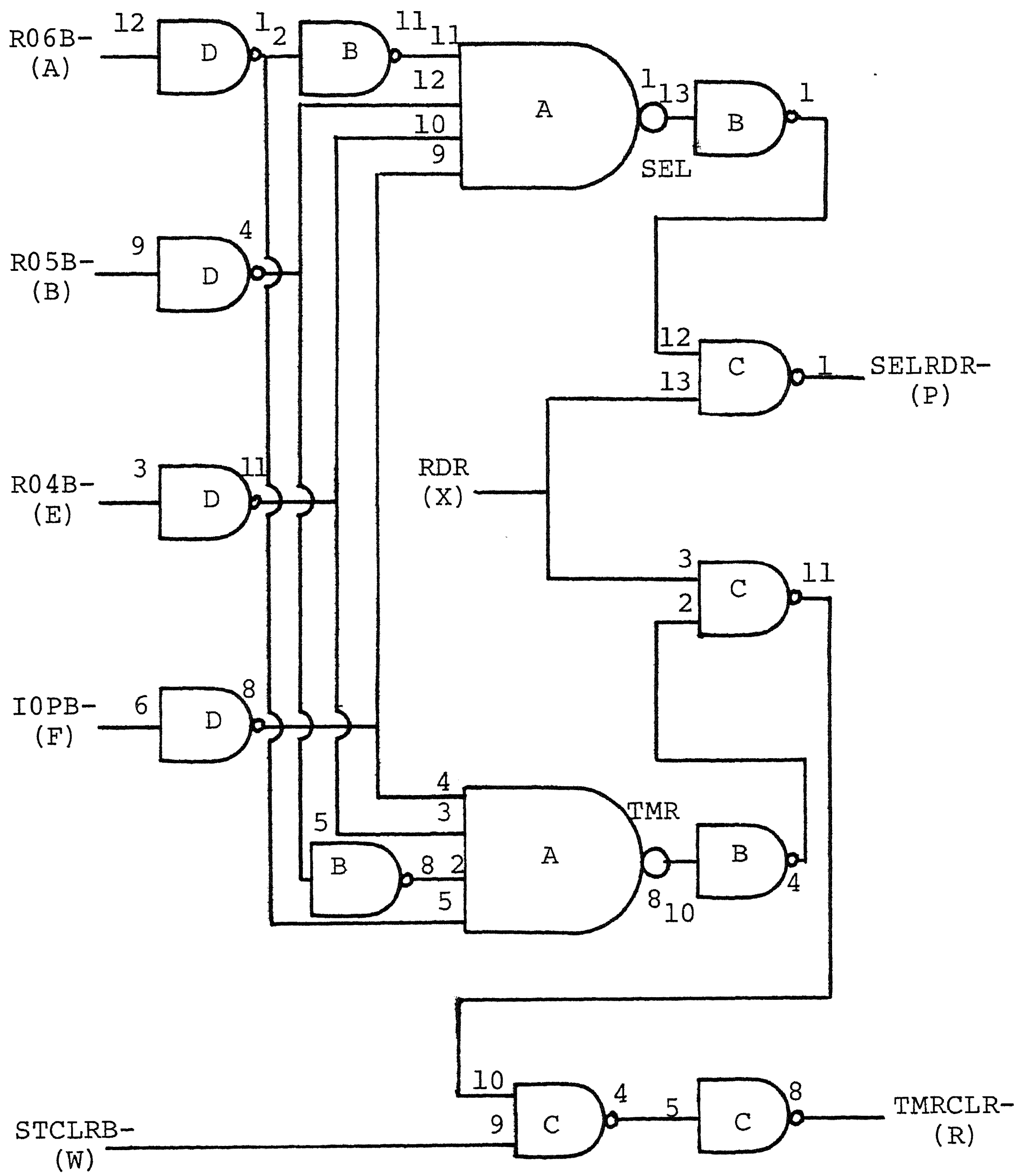


Figure 11. Logic Diagram Number 4

APPENDIX B

DETAILED DESCRIPTION OF THE COMPUTER PROGRAM

The computer program contains the input-output commands which cause the interface to enter data into the computer from the radar. When the system is first turned on, the program brings in the first four pieces of data and checks for a north pulse (NP). If the NP is not present, the program enters a wait loop and continues bringing in data and checking it until the NP arrives. This establishes a reference for the data.

Once the NP has arrived, the program starts accumulating target data by storing a 1 in the proper bit of a word in memory when a target is present in the corresponding range block. If no target is present, a 0 is stored in the proper bit. Once an 11 bit word is formed, it is coded in the first bit (bit zero) to form a 12 bit word. The word is then stored in a buffer area in memory, to be written on magnetic tape when time is available. Lightning information (azimuth and range) is also written at the end of each sector where lightning information is present.

An error detection scheme is included in the program which counts the bits in each sector, and limits a sector to a range of 55 to 70 bits, or range blocks. If the sector contains more than 70 bits of information, an error message is recorded on the magnetic tape.

The data on tape are separated according to revolutions by pseudo-gaps. A pseudo-gap consists of the octal number '7474 recorded on tape four times. The program also prints the revolution count at the beginning of each revolution. When a revolution is complete the program looks for another north pulse, to establish a new reference. If a north pulse fails to arrive at the proper time, the computer continues to wait until one arrives; therefore, a revolution of data may be lost periodically. This loss is of no serious consequence since a revolution is only 11.3 seconds long.

On the input lines to the computer, NP corresponds to bit 8, the ACP to bit 9, the TP to bit 10, and TGT to bit 11.

The program stores a one or a zero in the first bit of radar word (RDRWRD), which is a word in memory set aside for accumulating radar target information. A one in the first bit (bit zero) signifies the presence of a target in that range block and a zero signifies the absence of a target. The first piece of information is shifted into bit one (the second bit). The next piece of information is brought in, and another one or zero is entered into bit zero of RDRWRD. This recording of target information continues until eleven bits of information are accumulated. This word is then coded and either stored or written on magnetic tape, depending on the amount of time available. A new 11 bit word is then started.

There are 64 bits of information in each 1.4° azimuth sector; therefore, five 11 bit words and one 9 bit word are generated in each sector. The first bit of each word thus formed is used as a code bit for use when the magnetic tape is processed. These codes indicated where the north pulse is located in the string of data, where the start of each azimuth sector is located, and which pieces of data are the lightning stroke azimuth and range. The codes are as follows (see Figure 5): the first two 11 bit words will have a leading one attached (resulting in a 12 bit word) to indicate the location of the north pulse, and the remaining four words of the sector will have leading zeros. A one in the first bit of only a single word which was preceded and followed by words with leading zeros indicates the first word of an azimuth sector, excluding the first sector after the north pulse. The lightning azimuth word will have a leading one, as will the lighting range word. These two words can be distinguished from the first two words of the sector immediately following the north pulse, because the lightning information is printed only at the end of an azimuth sector.

As an example of the coding scheme, see Figure 5. Considering only the leading bit of each word, a 1 on the leading bit of the first two words followed by zeros on the remaining 4, then a 1 on the first bit of one word followed by zeros on the remaining 5, and a 1 on three words, followed by zeros on the remaining 5 would indicate the following: the sector immediately following the north pulse with no lightning information present in that sector, then the second sector with lightning data present, followed by the third sector.

The information being received from the radar set is sometimes in error due to the quality of the telephone line. Because of this, there may be sectors which contain more or less than 64 pieces of information. Investigation has shown that the error is approximately ±2 bits per sector. This possibility of error must be taken into account in the program to avoid losing the reference; consequently, the program allows a sector to be as short as 55 bits, or as long as 70 bits. To accomplish this, the program looks for an ACP after 55 bits are accumulated in a sector. If the ACP occurs before 64 bits are accumulated, the program accepts the information as a short sector and writes it on tape when time is available. If 64 bits are accumulated and an ACP has not yet arrived, the program enters a loop and starts counting the bits of information being received, and if, during the next six bits, or 70 bits total for the sector, the ACP arrives, the program accepts the information as a long sector and writes the sector on magnetic tape when time is available. If, after 70 bits have arrived, the ACP has still not occurred, the computer writes a gap on tape indicating a serious error occurred during that particular revolution, and then waits for another north pulse to start a new revolution.

One of the most challenging problems encountered in writing this program was that of timing. The magnetic tape recorder requires 6.67 milliseconds to write a 12 bit word. Execution time of the program is approximately 0.15 to 0.20 milliseconds. The radar set generates an 11 bit word every 7.59 milliseconds, and when lightning strokes occur, two more 12 bit words are to be written. As a result, if lightning stroke activity becomes frequent during a revolution of the radar antenna, there is more information to be written than the magnetic tape recorder can write before another timing pulse arrives. Because of this timing problem, there has to be a limit set on the number of lightning strokes per revolution. This limit will be realized by the lightning detectors and associated circuitry. The limit should cause no difficulties, as approximately 15 strokes per revolution, or slightly more than one stroke per second, can be processed.

A dynamic buffer had to be established in the computer's memory to hold data in the proper order until it could be written on magnetic tape. The data words are stored in the buffer area (queue), at the bottom of the buffer. When the magnetic tape is ready to write, the program writes the word from the top of the buffer area and moves all the remaining data words in the buffer up one position. When the next word is formed, it is stored at the bottom of the buffer. If there are no lightning words to be written, the data can be written slightly faster than it comes in. When lightning strokes are to be recorded, however, the write routine gets slightly behind, but the dynamic buffer avoids losing information coming in, and the magnetic tape unit will catch up shortly and empty the buffer area.

To insure that no meaningful data is lost, the four azimuth sectors preceding the north pulse are ignored, and this time (132 milliseconds) is used to make certain that the buffer area is empty before a new revolution is started. The data that is ignored in the four sectors is unimportant since the lightning detectors have very poor accuracy along the north-south line.

A lightning data program will have to be used for determining the azimuth and range of lightning strokes. Accommodations for the lightning program are included in the radar signal processing program. A "HALT" statement and a "JUMP BACK ONE" statement can be removed to provide space for the address of the lightning program, and storage of the status register. When the radar processing program has finished processing the current piece of information, it will jump to the lightning program. Once an interrupt is received from the radar set, the interrupt will cause the computer to re-enter the radar program to process the radar data.

The "wait for north pulse" loop is the first step in the program (see Figure 12). Once the north pulse occurs, the program checks to see if it should wait for an ACP. If WTACP has been set, the program checks for an ACP. If the ACP has arrived, WTACP is cleared and

WTLNTH is reset to allow six timing pulses to occur past the normal 64 pulses per sector. If the ACP has not arrived, WTLNTH is incremented and the program checks to see if it has waited for six timing pulses past 64. If it has, and no ACP has arrived, a gap is written to indicate the error. If the program has not waited for six timing pulses past 64, it brings in the next piece of information.

If WTACP is not set, or if the ACP arrives before 70 timing pulses are received, the program counts the timing pulse. The timing pulse count is provided for future use in processing the completed magnetic tape. If this is the fifth word of an azimuth sector, the program again checks for an ACP. If the ACP has arrived, WRTFLG is set to indicate to the program that the sector is finished and it is time to write the sector's information.

The next step in the program checks to see if a target was present in the range block being processed. If there was a target present, a one is entered in the corresponding bit of RDRWRD. If no target was present, a zero is entered. After the target information is entered in RDRWRD, the program again checks to see if this is the fifth word of a sector (see Figure 13). If it is the fifth word of a sector, the program checks to see if WRTFLG has been set. If WRTFLG has not been set, the bit is counted and then checked to see if this is the ninth bit of the sixth word (the 64th bit of a sector). If it is not the 64th bit, the program checks the buffer area and, if there are any words in the buffer, the program writes the word from the top of the buffer onto magnetic tape. If it is the 64th bit, WTACP is set to cause the program to wait for an ACP when the next piece of information enters the computer.

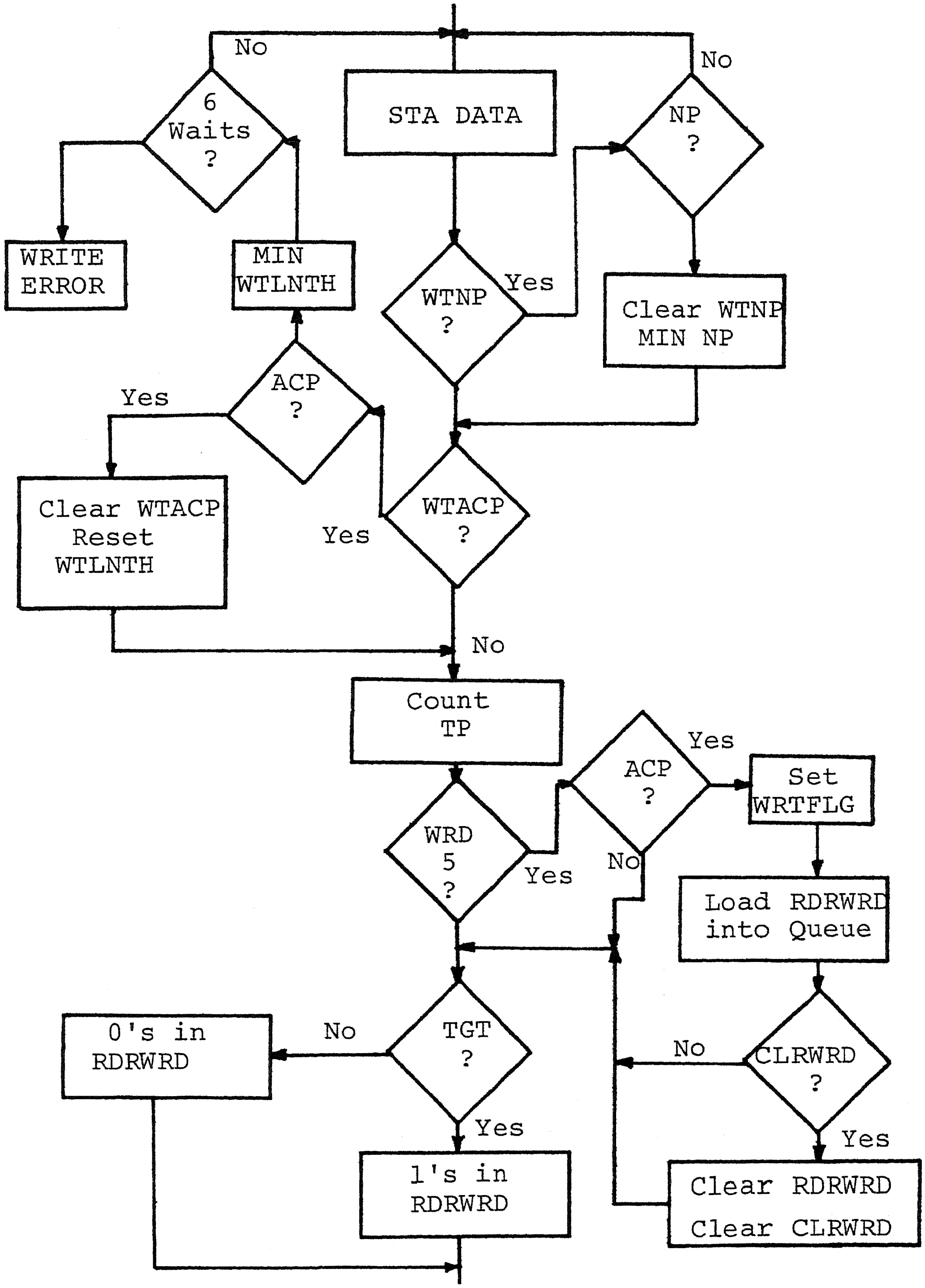
After the 64th bit has been received and WTACP set, or if WRTFLG has been set, the word in RDRWRD is loaded into the buffer area. BITCNT, WRDCNT, TPCNT, and WRTFLG are cleared and ACPCNT is incremented. The program then checks to see if this is the 252nd azimuth sector. If it is, ACPCNT is cleared and GAPFLG is set to indicate that it is time to write a pseudo-gap after the buffer is emptied. The psuedo-gap is used to separate the revolutions on magnetic tape. If this is not the last azimuth sector of the revolution, the program checks to determine if lightning data is present in the present sector. If there is lightning data present, the azimuth and range words of the lightning data will have their code bits attached by the program and then they will be stored in the buffer area, waiting to be written. If there was no lightning data present in the sector, the program would check to see if GAPFLG has been set, and if it has, the program would store the radar data in the buffer area and cause a pseudo-gap to be written. If GAPFLG had not been set, the program would make an attempt to write a word from the buffer area onto magnetic tape.

If this had not been word number five of the present sector, the program would check to determine if this was the eleventh bit of the present word (see Figure 14). If not, the program would check to see if there were words present in the buffer, and, if so, the program would attempt to write them. If there were no words in the buffer, the program would return to the area allotted to the lightning program.

If the present piece of information was the eleventh bit of the word, then the program would increment WRDCNT, clear TPCNT, and check for the first word of a sector. If it was the first word, the program would check to see if the north pulse was present, and, if not, the program would attach the code bit to the word. If the north pulses had been present, the first bit of the first word would be coded and NPFLG set.

If this was not the first word, the program would check to determine if it was the second word. If it was not, the word would be loaded into the buffer and the program would make an attempt to write from the buffer onto tape. If this had been the second word, NPFLG would be checked. If NPFLG was not set, the program would try to write. After each attempt at writing, the program returns to the area allotted to the lightning program. If NPFLG has been set, the first bit of the word would be coded, NPFLG would be cleared and the program would attempt to write.

Refer to CRL Technical Report Number 70.1 for the computer program.



(next page)

Figure 12. Program Flow Chart Number 1

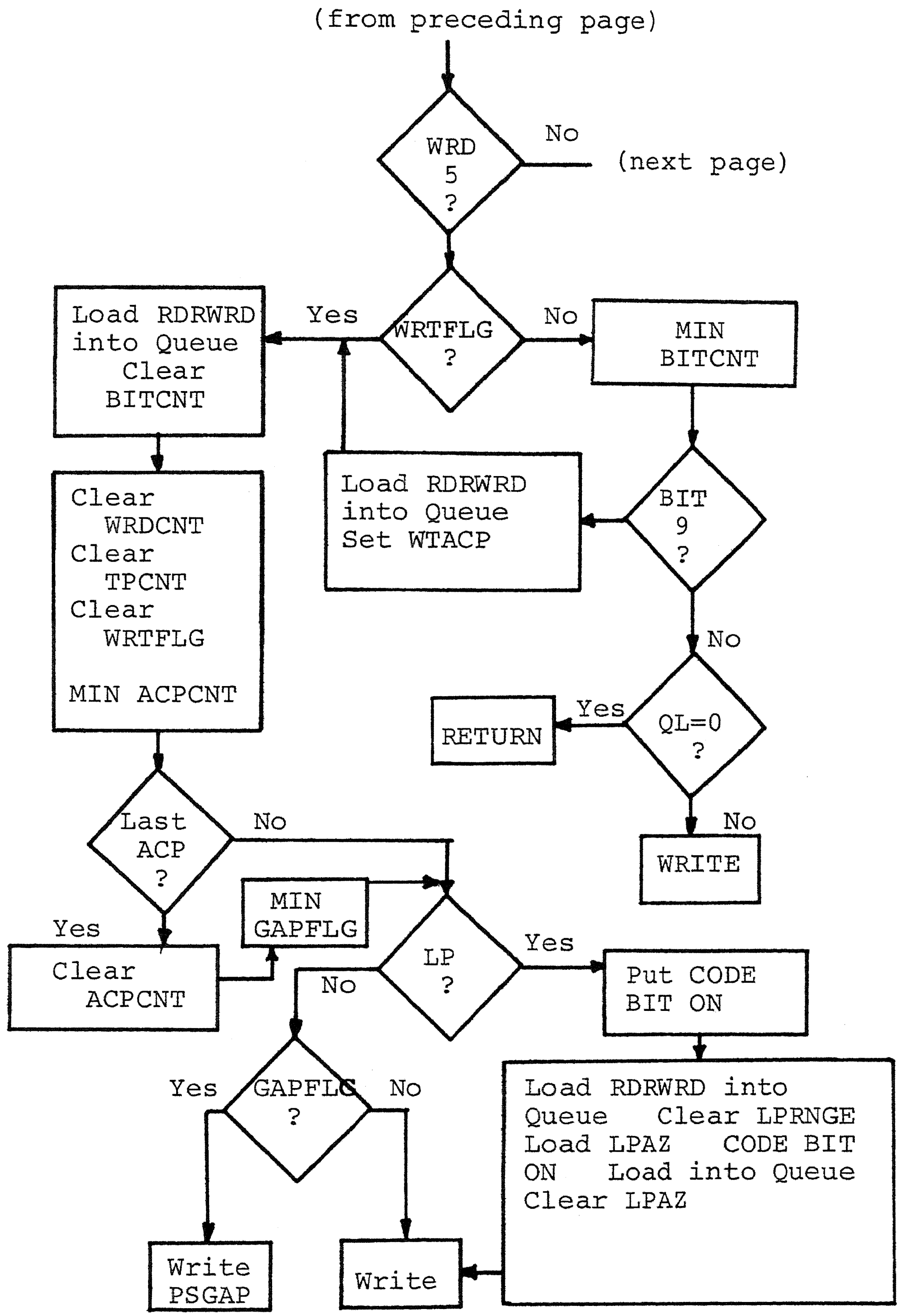


Figure 13. Program Flow Chart Number 2

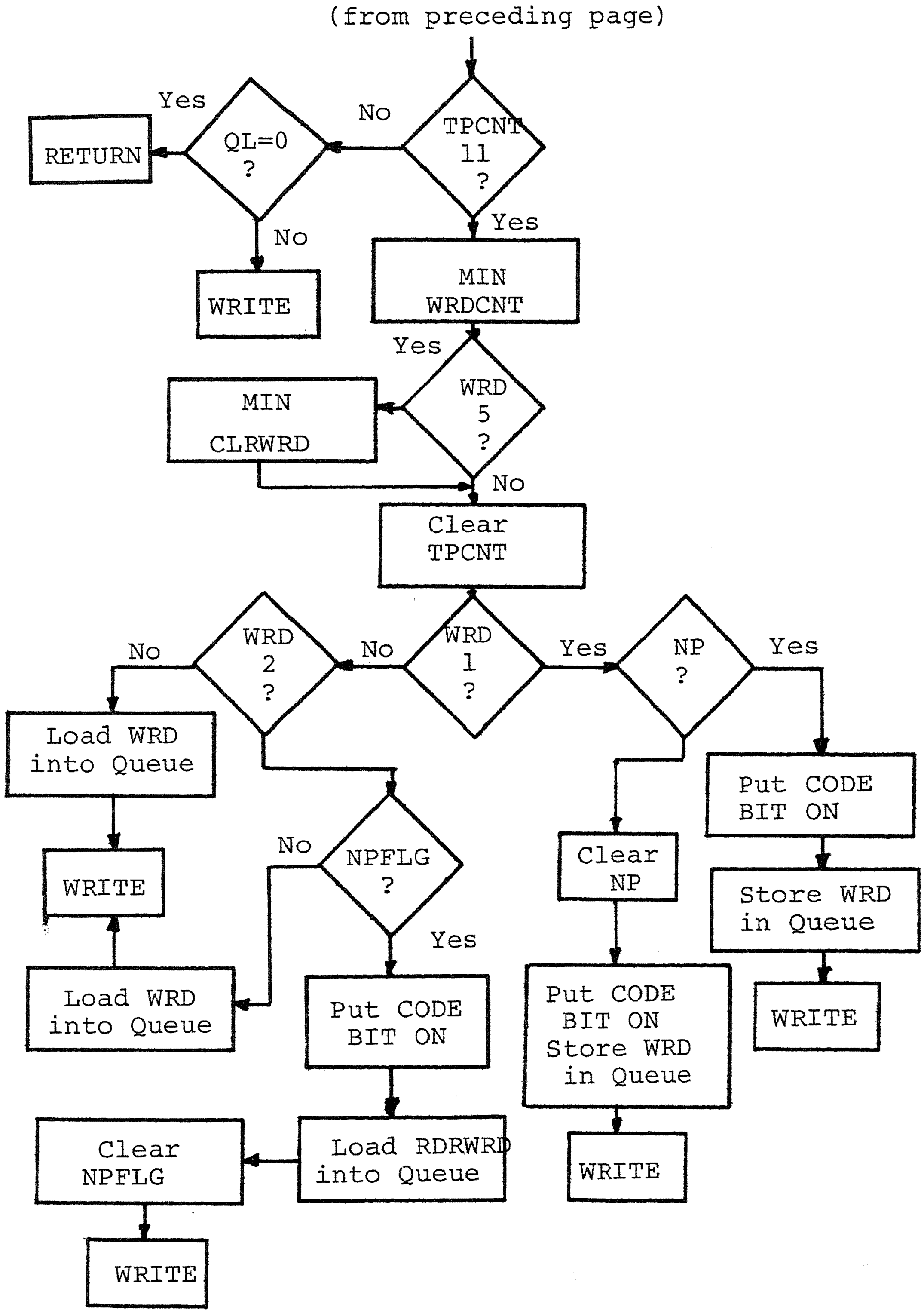


Figure 14. Program Flow Chart Number 3

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VIII. VITA

Gary Wayne Neal was born on November 16, 1940, in Murphysboro, Illinois. He received his primary education at DeSoto, Illinois, and his secondary education at Carbondale, Illinois. He was a member of the United States Air Force for five years, and attended Gulf Coast Junior College, Panama City, Florida, for one semester during his enlistment. The remainder of his undergraduate training was received at the University of Missouri - Rolla, where he was granted the Bachelor of Science degree in Electrical Engineering in January, 1969.

After having received the bachelor's degree, he became a graduate Teaching Assistant at the University of Missouri - Rolla, where he was concurrently enrolled in the Graduate School.